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GROWTH, DIGESTIBILITY AND DEVELOPMENT OF RUMEN FUNCTION IN HOLSTEIN CALVES

by

(C) JAMES DOUGLAS MILLIGAN

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Growth, Digestibility and Development of Rumen Function in Holstein Calves" submitted by James Douglas Milligan, B.Sc., in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

A study of different levels of milk replacer feeding indicated that gains by calves to weaning at 4 weeks of age could be doubled by feeding milk replacer to maximum appetite as compared to restricted feeding. These calves maintained their weight advantage to the end of the test at 120 days of age. A complex pre-starter decreased post-weaning growth due to decreased feed consumption as compared to a simple calf meal. Feeding pelleted starter rations from 10 days to 10 weeks of age as compared to feeding unpelleted rations reduced performance of calves to 4 weeks, 8 weeks and 120 days of age due to reduced feed intake and utilization.

Chromic oxide served as a suitable indicator of fecal excretion for digestibility studies with calves at 4 and 8 weeks of age. However, dry matter digestibility coefficients were underestimated due to incomplete recovery of the chromic oxide that was fed; this was most noticeable with calves at 4 weeks of age. A study of excretion patterns showed that although their was very little intra-day or between day variation in chromic oxide concentration in the feces, calves at 4 weeks of age required a 4-day instead of a 3-day adjustment period in which chromic oxide was fed before feces were sampled.

Digestibility studies at 4 and 8 weeks of age indicated that there were no differences in the ability of calves to digest either pre-starter or calf meal. The digestibility of rations by calves increased substantially from 4 to 8 weeks of age. Pelleting starter rations decreased their digestibility by calves at both 4 and 8 weeks of age; the decrease being greatest with calves at 4 weeks of age.

Changes in individual and total rumen volatile fatty acid levels, rumen pH, and blood glucose concentrations were studied with four calves from 6 to 55 days of age. The individual acids started to increase in concentration in the order of their increasing carbon chain lengths and they reached their maximums in the order of their decreasing carbon chain lengths, thus indicating the order of absorption and metabolization by the rumen tissue. Rumen pH decreased as the total volatile fatty acid level increased; both reaching an equilibrium at approximately 37 days. Blood glucose concentrations remained relatively high due to a glucogenic effect caused by high levels of propionate.

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INTRODUCTION

The customary method of rearing dairy calves is to feed them low levels of whole milk for several months plus <u>ad libitum</u> levels of a high roughage ration to a year of age or more. Feeding whole milk is expensive as compared to feeding milk substitutes and feeding a liquid diet, in general, is a predisposing factor to digestive disturbances and serious secondary infections unless the degree of sanitation is exceptionally high. Therefore, it is advantageous to feed milk or milk substitutes for as short a period as possible.

Early workers felt that high roughage calf rations were necessary for the proper development of rumen function and to take advantage of the ruminants' ability to utilize low cost fibrous feeds. Recent work has indicated that high concentrate calf rations lead to a greater stimulation of rumen function; thus allowing calves to be weaned at an early age.

Work has been carried out at the University of Alberta over the past few years in the study of rearing techniques which involved the feeding of milk substitutes from less than 1 week of age and the use of high concentrate starter rations in weaning calves at an early age. Once calves were weaned, growth rates were equivalent to normal standards and digestive disturbances were minimal. The optimum level of milk replacer to feed and the most suitable weaning age were questioned due to set-backs in weight that occurred during weaning with the various systems of rearing calves that were studied. Workers in swine nutrition at the University of Alberta avoided a large set-back in growth due to early weaning by feeding a complex pre-starter ration to weanling pigs.

As a result, the present study was undertaken at the University of Alberta to study the feeding of either restricted or high levels of milk replacer, to compare calves weaned at different ages, to compare a complex pre-starter ration to a simple calf meal used in weaning calves, and to determine the digestibility of rations by calves at different ages. In relation to the above, the use of chromic oxide as an indicator of fecal excretion and the development of rumen function was also studied.

REVIEW OF LITERATURE

A. Digestion In The Ruminant

1. General

The digestive tract of animals includes the mouth, the esophagus, the stomach, the small intestine, and the large intestine (Morrison, 1959). Digestive fluids are secreted into the tract from glands in the membranes lining the stomach and the intestinal tract, and from the liver and the pancreas. In ruminants, such as cattle, sheep and goats, the stomach portion is divided into four distinct compartments instead of a single simple stomach as in monogastrics such as the pig. The first and also the largest compartment is the rumen, followed by the reticulum, the omasum, and finally the abomasum. Enzymes and other digestive fluids are secreted into the abomasum where digestion is similar to that in the gastric stomach of monogastric animals.

2. Pre-weaning digestion

Owing to reflex closure of the esophageal groove which gives a direct route for passage of milk to the abomasum in the newborn calf, the rumen is a rudimentary, relatively insignificant organ (Flatt, Warner, and Loosli, 1959; Phillipson, 1958). In the newborn calf the rumen and reticulum together are only about half as large as the abomasum, as compared to a mature animal in which the rumen accounts for about 80 per cent of the total stomach volume (Annison and Lewis, 1959). The capacity of the rumen of adult cattle varies greatly with age and size of the animal, but is usually in the range of 100 to 300 liters.

In the newborn calf, as in the monogastric, milk carbohydrates, proteins and fats are enzymatically degraded to glucose, amino acids, and fatty acids and glycerol, respectively. These ends products are absorbed

relatively unchanged through the epithelial cells of the small intestine.

The efficiency of digestion of carbohydrates other than lactose (milk sugar) may not be as high in the gastric stomachs of calves as in monogastrics because of differences in enzyme secretions. Bailey, Kitts and Wood (1956) studied the changes that occur in the saccharolytic enzyme complex of the suckling pig and reported that lactase activity was high at birth and through the first 2 weeks of life at which time the activity declined, reaching a mimimum at 3 to 4 weeks of age. Sucrase and maltase activities were found to increase from negligible levels at birth to maximum levels after about 25 days. These marked changes suggested that different carbohydrate sources could be utilized in accordance. Huber, Jacobson and Allen (1961) studied enzyme activities in the calf from 1 to 44 days of age and found that intestinal lactase activity was highest at 1 day of age and decreased thereafter. Intestinal maltase levels were low at 1 day and did not change with age, and no intestinal sucrase was detected. Additions of lactose, sucrose and starch to the diet did not affect enzyme levels. Baldwin and Ronning (1966) studied enzyme activities in livers of calves and rats fed high carbohydrate and low fat diets. They found an absence of dramatic enzymatic changes of the saccharolytic complex of calves as compared to changes observed in a similar study with rats. They concluded that metabolic responses of calves to changes in carbohydrate and fat intake are much more limited than in the rat.

3. Adult ruminant digestion

Digestion in the adult ruminant differs greatly from that of the adult monogastric. Blaxter (1962) estimated that 2/3 to 3/4 of the ruminants' energy was obtained directly from the rumen. As the rumen develops, a mixed population of bacteria and protozoa becomes established (Annison and Lewis, 1959; Lewis, 1961; Phillipson, 1958). These microorganisms live in symbiosis with the host by converting feedstuffs into readily utilizable

forms. Carbohydrates are degraded to volatile fatty acids (VFA) which are absorbed directly from the rumen and utilized as the major energy source in ruminant metabolism. The end products of protein degradation are VFA and ammonia. The rumen microorganisms are able to utilize simple nitrogenous substances such as ammonia for the synthesis of their body proteins. These organisms ultimately pass from the rumen to the abomasum and small intestine where protein is digested and absorbed as in the non-ruminant.

It has been demonstrated that digestion in the calf is similar to that in the pig in pre-weaning stages but is very different in later stages. However, the status of the calf's digestion at the time of weaning is not understood. Some workers feel that solid feeds are of little use to the calf until the rumen is functioning (Flatt, Warner and Loosli, 1959) and this may be due to the lack of response of enzyme changes in the calf. Nevertheless, it is obvious that in weaning pigs one is taking advantage of enzyme changes to utilize cheaper feeds whereas in weaning calves one is taking advantage of the physiological and microbiological changes which occur in the developing rumen.

B. Rumen Development

Rumen development is not only a simple enlargement of the organ, but involves development of a vast microbial population, production and utilization of VFA, an increase in musculature, and development of mucosal or papillary tissue.

1. Importance of rumen development

An estimated 70 to 85 per cent of the digestible dry matter was utilized in a fully functional rumen (Gray, 1947), thus indicating its importance in nutrition of the calf. To illustrate the importance of a

functional rumen, Stewart and Henning (1965) transected and sewed the esophagus to the abomasum of young calves. The abomasum enlarged somewhat but the rumen remained rudimentary and as a result all the calves died within 6 months of age due to malnutrition. Nicolai and Stewart (1965) found no rumen development and greatly reduced gains when calves were fed through abomasal fistulae from 1 week to 90 days of age.

As long as food by-passes the rumen due to the reflex closure of the esophageal groove, it is apparent that there is little or no development of this organ. Hegland et al (1957) demonstrated that calves lost this reflex ability as early as 3 or 4 weeks of age when dry feeds were eaten or at about 13 weeks of age when only liquids were fed. Wing (1965) was able to inhibit any further rumen development for 11 months by feeding steers only whole milk. With starter rations available from 3 days of age, calves had consumed sufficient solid feed to develop functional rumens by 3 weeks of age.

2. <u>Microbial development</u>

The mechanism by which the microbial population develops is not clearly understood, but is believed to be due to inoculation by the various solid feeds given and by contact with other animals (Annison and Lewis, 1959). Cuds or rumen fluids from adult ruminants have been used to inoculate calves (Conrad and Hibbs, 1953; Conrad, Hibbs and Frank, 1958; Hardison, Miller and Graf, 1957; Hibbs and Conrad, 1958). Although bacterial populations have been altered, no benefit in promoting rumen function has been demonstrated.

Early workers believed that good hay was necessary to establish a proper microbial population (Conrad and Hibbs, 1953). Although the microbial population that was established from feeding roughage to calves was more like that of adult ruminants due to the increase in cellulolytic organisms, it was not necessarily advantageous. Addanki, Hibbs and

Conrad (1966b) found that calves fed roughage diets digested very little cellulose until about 10 weeks of age. Recent work has shown that large bacterial populations were established as early as 4 weeks of age when concentrates alone were fed and that the rumen microbial population could adapt readily to new diets (Harrison et al, 1960; Stobo, Roy, and Gaston, 1966).

3. VFA production

The end products of microbial digestion are the volatile fatty acids (VFA). They are found in all parts of the digestive tract of the young calf, but significant quantities are not produced without a functional rumen (Huber and Moore, 1964; Ndumbe, Runcie and McDonald, 1964). In mature cows the main acids are acetate, propionate and butyrate in approximate mole percentages of 66, 22 and 12%, respectively (Mackay, 1963).

Both roughage and concentrate diets lead to VFA production, but with different molar ratios of the individual acids. Stobo, Roy, and Gaston (1966) found that in calves fed concentrate diets the mole percentages were 47.5, 28.4, 12.8, and 9.0%, for acetate, propionate, butyrate, and valerate and higher acids, respectively, as compared with corresponding values of 73.4, 18.0, 6.8, and 0.2%, for calves fed all-hay diets. Omar, Reagor and Kunkel (1964) showed that in lambs the proportion of acetate was negatively related to the level of total VFA and the stage of rumen development. They found that the displacement of acetate, which occurred in lambs fed a higher concentrate ration, was due to increased propionate and butyrate concentrations.

Although the usefulness of molar ratios of VFA in the rumen is limited because they represent a balance between production, absorption and excretion, a better understanding of rumen function has been obtained from their study. Stobo, Roy and Gaston (1966) studied the changes in VFA levels after feeding calves either a high concentrate or a high

roughage meal. The concentration of total VFA in rumen fluid rose steadily from time of feeding to a peak at about 3 hours after feeding and tended to be higher in calves given high concentrate diets. There was a distinct tendency for the molar percentages of propionate and butyrate to increase at the expense of acetate; the trend being more pronounced in the calves fed high concentrate diets. As the total VFA concentration declined, the molar percentages of propionate and butyrate also fell. The results suggested that greater amounts of VFA, especially propionate and butyrate, were produced and absorbed in calves fed high concentrate diets as compared to high roughage diets.

4. Development of absorptive ability

Martin et al. (1959) reported that calves were able to absorb significant amounts of VFA by 3 weeks of age when fed a concentrate ration containing VFA salts. Sutton, McGilliard and Jacobson (1963) studied the absorption of VFA from the rumens of young calves fed either milk or milk, hay and grain (MHG) diets from 1 to 13 weeks of age. The maximum absorption rate of acetate was negligible in all calves at 1 week of age and in milk fed calves no change was found to 13 weeks of age. In contrast to this, the absorption of acetate from the rumen increased markedly in the MHG fed calves up to 13 weeks. Absorption of propionate and butyrate were not studied at earlier ages, but a trial at 16 weeks showed that the relative absorption rates were butyrate > propionate > acetate. A lowering of pH from 7.5 to 5.5 markedly increased absorption rates, with butyrate being affected most. Other workers have shown that high concentrate diets result in lower ruminal pH levels than do high roughage diets (Hibbs et al. 1956; Stobo, Roy and Gaston, 1966). Although Sander et al. (1959) suggested that no preferential absorption of VFA occurred, the above work of Sutton and co-workers clearly indicated that absorption was not passive. They suggested that absorption was related to the metabolic activity of the

rumen mucosa.

5. Development of muscle and mucosal tissue

Early workers felt that the physical stimulation caused by feeding roughage was necessary for the papillary and structural development of the rumen (Conrad and Hibbs, 1953). However, the feeding of bulky indigestible materials such as peat moss and nylon bristles greatly increased rumen volume, but did not stimulate papillary development (Brownlee, 1956; Warner, Flatt and Loosli, 1956). Harrison et al. (1960) fed calves to 38 weeks of age on diets of milk, milk plus wood shavings, 90% concentrates and 90% hay. Weights were obtained of 0.61, 0.85, 2.30 and 2.02 g/dcm^2, respectively, for mucosal tissue in the rumen lining and 1.36, 2.28, 2.02 and 2.58 g/dcm^2, respectively, for muscle tissue. It was apparent that the concentrate ration stimulated the greatest growth of mucosal tissue and the roughage diets stimulated the greatest growth of muscle tissue. It was concluded that mucosal and muscular development were independent; mucosal growth likely being stimulated by VFA and muscular growth being stimulated by ruminal fill.

Sander et al. (1959) fed calves on milk and milk plus equal molar portions of either acetate, propionate or butyrate and studied the subsequent growth of mucosal and muscular tissue in the rumen. The amount of mucosa in rumen tissue increased from 32% by weight in the control calves fed milk to 48, 60 and 66% in the calves supplemented with acetate, propionate and butyrate, respectively. These differences were due to increased weights of mucosal tissue, whereas the weights of muscular tissue remained constant. This confirmed the hypothesis that mucosal development was stimulated by VFA in the rumen.

Sutton et al. (1963) studied the metabolic activity of mucosa from rumens of 16-week-old calves fed either milk or milk, hay and grain (MHG) diets. Tissue slices were used to demonstrate that mucosal

tissue from MHG-fed calves metabolized VFA to a much greater degree than mucosal tissue from milk-fed calves. Butyrate was shown to be metabolized more than propionate and both acids were metabolized more than acetate.

Dobson and Phillipson (1956) showed that an increased VFA level in the rumen increased blood flow from the rumen, with butyrate having the greatest stimulatory effect. This was believed to be associated with rapid tissue growth and absorption. It has been shown that if a continual diet of concentrates was not supplied the rumen papillae would rapidly regress towards their undeveloped state (Harrison et al., 1960; Stobo, Roy and Gaston, 1966). These results implied that the development of rumen function was not merely stimulated, but must be maintained also.

5. Blood glucose and VFA metabolism

Blood sugar or glucose levels have been thought to be closely related to rumen development as several workers have observed a relative hypoglycemia in calves between 3 and 8 weeks of age (Conrad and Hibbs, 1953; Ndumbe, Runcie and McDonald, 1964). Blood sugar levels in adult ruminants were estimated to range from 36 to 57 mg % which were about one-half the levels observed in the newborn calf (Barnett and Reid, 1961).

Jacobson, Allen and Bell (1951) observed hypoglycemia in milk-fed calves as well as in high-roughage-fed calves and concluded that the ruminant possesses a characteristic developmental change towards hypoglycemia independent of the feeding program. Nicolai and Stewart (1965) found no significant differences in the glycemia pattern of calves that were fed either milk orally, milk, hay and grain orally or milk, hay and grain through an abomasal fistula. The average blood reducing sugar level for all calves decreased from 92 to 67 mg % from

1 to 90 days of age.

Stobo, Roy and Gaston (1966) studied the blood plasma glucose levels in calves fed either an all-concentrate or an all-hay diet. The overall mean concentrations of plasma glucose were 92.8 and 67.5 mg % for the all-concentrate and all-hay fed calves, respectively. They attributed the absence of hypoglycemia in the all-concentrate-fed calves as due to the glucogenic effect of high levels of propionate. Reid (1950) had previously shown that propionate was removed by the liver with the production of glucose and thus it was concluded that a calf given a diet consisting mainly of roughage utilizes considerable amounts of acetate as a source of energy to the tissues, whereas the calf given a high concentrate diet relies more on glucose as its energy source.

The metabolism of acetate, propionate and butyrate was studied in young milk-fed calves by intravenous infusion of the various acids (Young, Tove, and Ramsey, 1965). All calves were able to metabolize relatively large quantities of all three acids at similar rates. Acetate and butyrate resulted in increased ketone production whereas propionate caused decreased productinn. Contributions to blood glucose labelling from propionate and butyrate were equal and greater than from acetate. Recent studies have indicated that adipose and muscle tissues were the main sites of acetate oxidation and utilization in the ruminant, whereas the liver had only limited ability to utilize acetate (Anonymous, 1967 a).

C. Milk And Milk Requirements

1. Colostrum

Colostrum is the milk secreted during the first few days of

lactation. It provides passive immunization against various infectious diseases of the young calf (Roy, Huffman and Reineke,1957). This is due to immune lactoglobulins that are found in the aqueous phase of the colostrum.

Colostrum also contains high levels of vitamins, minerals, proteins, and energy which aid in giving the calf an optimum start in life. Roy and co-workers (1957) studied the basal metabolism of the newborn calf and found that heat production was high the first 2 to 4 days of life and then it fell rapidly to the eighth day. They hypothesized that the calf requires the higher energy that is obtained from colostrum during the first few days of life to meet its higher energy requirements. It is generally agreed that 3 to 5 days of colostrum feeding is essential.

2. Whole milk

Blaxter and Wood (1952a) studied the nutritive value of cows' whole milk and found the apparent digestibility of nitrogen, fat and energy to be 93.8, 95.6 and 95.0%, respectively. Leche (1964) found whole milk contained 723 kcal metabolizable energy per kg which agreed closely with values determined by Blaxter and Wood (1952) for whole milk with 4% fat. Gonzalez-Jiminez and Blaxter (1962) found the metabolizable energy of milk to be 95% of gross energy for calves during 11 to 29 days of life. The net availability of the metabolizable energy was 80 per cent. Roy et al.(1958) obtained a net energy value for cows' milk of 68.5% when fed to 25-day-old-calves. Using a basal metabolic rate of 51 kcal/kg/24hr, they calculated the maintenance requirement for a 35kg calf to be 1771 kcal digestible energy (DE)/24 hours. This agreed with their experimental values which also indicated that an additional 307 kcal DE/24 hr was required for each 100g daily gain.

Under special experimental conditions, Leche (1964) was able to induce calves to consume milk according to the formula; $MO = 470\ W_{kg}^{0.75}$, where MO was milk intake and Wkg was weight in kilograms. This amounted to a 60 kg calf consuming about 10 kg of whole milk daily. Gains to a weight of 113 kg under this program of feeding were over 1 kg/day.

3. Synthetic milk

It has been demonstrated at the University of Alberta (Grieve, 1965, 1966, and 1967) and elsewhere (Brumbaugh and Knodt, 1952; Stone, Rennie and Ingram, 1963) that dairy calves can be raised successfully by feeding milk substitutes from as early as 4 days of age.

Milk replacers are composed of various mixtures of dried skimmilk powder, whey powder, fat, vegetable carbohydrates, and vitamins (Stone, Rennie and Ingram, 1963). Since fat is the best means of supplying energy and the natural fat in milk cannot be economically reconstituted, other sources of natural fat have been studied (Carroll, 1958; Deuel, 1951; Raven and Robinson (1964). The length of the carbon chain in the fatty acids should not exceed 18 carbon units and the particle size should not exceed 50 to 100 microns, so that the fat is easily emulsified and digested due to its larger surface area. The melting point of the fat should not be greater than 48° to 50° C. Hopkins, Warner, and Loosli (1959) studied the growth of calves fed milk substitutes containing fats from different sources. They found that when hydrogenated vegetable oils plus soybean lecithin in a 9:1 ratio was fed as the fat source in milk replacers, growth was comparable to that with whole milk feeding. However the level of fat that can be added is limited due to feeding problems and digestive disturbances (Stone, Rennie and Ingram, 1963).

The essential fatty acid requirements of the calf are low and thus sufficient levels are usually present (Cunningham and Loosli, 1954).

As the milk replacer has to be stored, the fat has to be stabilized to prevent oxidation and rancidity (Adam et al., 1959; Blaxter, Watt and Wood, 1952b). Antioxidants such as butylated hydroxytoluol and the free tocopherols (Vitamin E) have been used successfully.

The young calf requires a source of protein that can be enzymatically digested to supply all the essential amino acids. The milk proteins, whey and casein, have to be the young calf's major protein sources as it cannot readily hydrolyze other types of protein until about 3 weeks of age (Blaxter and Wood, 1952; Brumbaugh and Knodt, 1952; Noller, 1956).

Lassiter et al.(1963) studied the effect of protein level in milk replacers on growth and metabolism. Diets of 30, 24, 19, and 16% protein gave daily gains of 0.68, 0.80, 0.73 and 0.60 lb/day, respectively. This, along with nitrogen retention studies, indicated that 24% protein in milk replacers gave most satisfactory results.

Lactose, being the natural sugar in milk, is the major carbohydrate digested by young calves (Dollar and Porter, 1957; Huber, Jacobson and Allen, 1961). Dollar and Porter (1957) fed aqueous glucose, lactose, sucrose, dextrin and starch at a daily rate of 4.4 g/Kg bodyweight. During the first 4 weeks of life only glucose and lactose were utilized. Supplemental lactose levels of 5 and 10% of the dry rations were beneficial (Flipse and Huffman, 1950), while levels of 20 and 30% caused digestive disturbances (Riggs and Beaty, 1947).

Production from milk replacers has generally been less than that reported with whole milk (Adams et al., 1959; Asplund, 1963; Stone, Rennie and Ingram, 1963); however, various attempts have been made to improve available milk substitutes. Lassiter, Denton and Bastin (1955) found no beneficial effects from adding surfactants, although they obtained

some response in growth from adding antibiotics as was noticed by Hibbs and Conrad (1958) in whole milk diets. Bush et al.(1966) found a disadvantage for pelleted versus liquid milk replacer feeding. Horton (1966) found no beneficial effect by supplementing milk replacers with various levels of propylene glycol as an energy source.

D. Calf Rations

1. Weaning

Although many workers agree that calves can be induced to digest dry feeds by 3 weeks of age, the optimum weaning age is debatable(Grieve, 1965; Otterby and Rust, 1966; Sutton et al., 1963 ; Wing, 1965). Jacobson and Hatton (1966) weaned calves from whole milk at 3, 10, 17, 24 and 52 days of age. They obtained daily gains of 1.25, and 1.34 lb for males weaned at 3 and 10 days of age, and 1.08, 1.23, and 1.37 lb for calves of mixed sexes weaned at 17, 24 and 52 days of age, respectively. For the same weaning ages, death rates were 31, 6, 3, 5 and 3%, respectively. They indicated that a lower rate of gain the first 3 weeks of life led to a lower rate of gain to 12 weeks of age. Asplund (1963) found a similar set-back to 4 months of age among the smaller calves that were weaned at 3 weeks of age. Wing (1965) weaned calves from a skimmilk-colostrum diet at 3 weeks of age without serious set-backs when a high concentrate starter ration was available to calves from 3 days of age. He found they started to consume the starter ration after 1 week of age.

Some workers advocate a longer milk feeding period as older calves are not as severely affected by weaning (Conrad and Hibbs, 1953; Stone, Rennie and Ingram, 1963). This was especially noticed when calves were weaned and fed a high roughage diet. As roughage requires more extensive digestion and is lower in digestible energy than concentrates,

it was felt that it was of little use to calves 3 to 5 weeks of age (Otterby and Rust, 1966).

Workers in swine nutrition have avoided a large set-back due to early weaning by using highly concentrated and palatable pre-starter rations (Bowland, 1965).

2. Plane of nutrition

Bonnier and Hansson (1945) used monozygous twins to study the growth of calves from 30 to 810 days of age when fed on a high or a low plane of nutrition. Although the high plane calves had a greater rate of growth, both sets of calves had similar body measurements on a weight basis. Crichton, Aithen, and Boyne (1959) reared heifers with either a high plane of nutrition to 24 months of age, a low plane of nutrition to 24 months of age, a high plane to 44 weeks of age followed by a low plane to 24 months of age, or a low plane to 44 weeks of age followed by a high plane to 24 months of age. Later maturing characters such as liveweight and heart girth were affected most by restriction. Low plane calves were much less efficient in utilization of feed for weight gains. The order in which the calves developed sexual maturity was high plane, low-high plane, low plane and high-low plane. The results indicated that calves should be raised on a high continuous plane of nutrition for early sexual maturity.

3. High roughage rations

Workers at the Ohio Agricultural Experimental Station have published a series of reaearch papers centered upon a high roughage system for raising calves based on the early development of rumen function. Their objective was to take early advantage of the inherent capacity of the young ruminant to consume and digest large amounts of low cost fibrous

feeds (Conrad and Hibbs, 1953). Work to date has shown that a hay to grain ratic of 2:3 resulted in increased nitrogen retention, weight gains, total digestible nutrient intake, efficiency of food utilization and percentage of protein digested as compared to hay to grain ratios of 3:2 or 4:1 (Conrad and Hibbs, 1953; Hibbs et al, 1956). Although calves raised with high roughage diets, were not weaned from whole milk until 8 to 16 weeks of age, characteristic signs of a developing rumen were observed as early as 3 weeks (Hibbs and Conrad, 1958). Cud inoculations have increased the number of cellulose digesting microorganisms, but no improvement in performance has been demonstrated (Conrad and Hibbs, 1953; Conrad, Hibbs and Frank, 1958; Hibbs and Conrad, 1958). A study of various roughage sources indicated that pelleted alfalfa meal increased performance of calves as compared to pasture or grass silage (Conrad and Hibbs, 1956). Addanki, Hibbs, and Conrad (1966a and 1966b) compared sources of roughage in pelleted rations. Soybean flakes and beet pulp were superior to alfalfa in digestibility, total digestible nutrient intake and rate of gain by calves 8 to 16 weeks of age.

Other workers have also studied roughage feeding systems for raising calves. Gorrill (1963) found that calves fed either whole milk or milk replacer gained 1 lb/day to 9 weeks when placed on pasture from 2 weeks of age. Calves benefited more from pasture than from hay due to selective grazing and higher digestibility of the feed consumed. Hardison, Miller and Graf (1957) found that restricting grain in a high roughage ration did not affect weight gains to 4 months of age. Although, Rice and Paules (1965) found a 50% hay ration to be comparable in terms of weight gained by calves to an all-concentrate ration, recent

workers have clearly demonstrated the advantages of concentrate feeding over roughage feeding in terms of weight gained, feed efficiency and development of rumen function (Otterby and Rust, 1966; Sander et al., 1959; Stobo, Roy and Gaston, 1966).

4. Ration improvement

Factors influencing the acceptability and performance of calf starter rations have been studied. Newman and Savage (1938) found that dairy calves, 2 to 6 weeks of age, grew at slightly lower rates when fed a pelleted starter ration as compared to an unpelleted ration. Pelleting high concentrate rations has been shown to have no nutritional advantage in calf rations (Gardner, 1967; Lassiter et al. 1955). Pelleting high roughage rations may have some nutritional advantage due to increased intake (Conrad, Hibbs and Frank, 1958). Atai and Harshbarger (1965) demonstrated that sweetening with molasses, sucrose or dextrose increased feed consumption and growth. Gardner (1967) demonstrated that a simple starter composed of locally grown grains plus cottonseed meal and vitamins was eaten by calves in greater amounts and produced more rapid gains than a complex commercial starter ration.

E. Digestibility Studies

1. Measurement

The majority of literature published on the nutritive evaluation of feedstuffs has used apparent digestibility as the basis of comparison (Maynard and Loosli, 1962). For a particular dietary component, the amount of component in the feed minus the amount in the feces is an estimate of the amount of component apparently digested. Blaxter (1962) explained the limitations of apparent digestibility, one of which is

the numerous residues in the feces besides undigested feed.

A great deal of investigation has been directed towards the use of indicators in estimating fecal excretion of cattle so as to avoid laborious total collections (Chandler, Kesler and McCarthy, 1964; Elam, Putnam and Davis, 1959; McGuire, Bradley and Little, 1966; Miller, Perry and Cragle, 1966). The theory is that the indicator, which is an inert, non-absorbed material, is uniformly mixed with the feed and the nutrients in the gut and as a result is uniformly excreted.

2. Use of chromic oxide

Chromic oxide has been the most commonly used indicator in absorption tests or balance studies among the various classes of livestock (Anonymous, 1967b). The accuracy of this indicator method appeared to be limited in ruminants by the sampling error which may result when grab sampling of feces is employed (Elam, Putnam and Davis, 1959). The errors encountered are due to the large intra-day variation which occurs in the fecal excretion pattern of the indicator. Elam and co-workers studied the fecal excretion pattern of chromic oxide when it was mixed uniformly in a completely pelleted ration for beef cattle. Diurnal excretion occurred in animals limited-fed once daily, full-fed once daily, full-fed twice daily or fed ad libitum. They found a time concentration effect which appeared to be influenced by feeding schedule. They suggested that it was a reflection of the total time spent in the rumen due to the fact chromic oxide concentration would be lowest just after eating and highest after most of the nutrients were absorbed. Troelsen (1965) studied the release of chromic oxide in the rumen of sheep fed pellets of chromic oxide paper. He found a diurnal excretion pattern in which there was a tendency for a higher

concentration during the late morning and early evening and a low concentration in the early morning. The conclusion drawn by both groups of workers was that several samples taken at random times during the day over a period of several days were required to obtain an accurate estimate of fecal excretion.

McGuire, Bradley and Little (1966) avoided diurnal variations in steers by feeding a completely pelleted ration containing 0.5% chromic oxide at 4 hour intervals for several days. They found that digestibility coefficients calculated from chromic oxide concentrations were lower than the actual values determined by total fecal collection. This was partially due to a recovery in the daily feces of only 96.4% of the chromic oxide that was consumed per day.

EXPERIMENTAL

A. Objectives

Three experiments were designed to study growth, digestibility, and development of rumen function by young Holstein calves fed milk substitutes and all-concentrate rations. In two experiments, studies were conducted of the use of chromic oxide as an indicator of fecal excretion in determination of digestibility.

Specific experiments were designed to study:

(1) a) feeding different levels of milk substitutes,

b) a complex pre-starter as compared to a simple calf meal,

c) the digestibility of starter rations by calves at 4 and 8 weeks of age,

d) the use of chromic oxide as an indicator of total fecal excretion in determination of digestibility,

(2) a) unpelleted calf meal as compared to pelleted calf meal and pelleted pre-starter,

b) the pattern of excretion of chromic oxide, nitrogen and gross energy by calves fed all-concentrate rations,

(3) a) changes in rumen volatile fatty acids, rumen pH, and blood glucose levels in calves to 8 weeks of age.

B. Methods and Procedures

1. Animals and treatments

Experiment 1 was conducted from May to September, 1966, using 20 grade Holstein calves (10 males and 10 females) that were purchased locally. Experiments 2 and 3 were conducted from September, 1966 to March, 1967, using 12 and 4 Holstein calves, respectively, born at the University

of Alberta livestock farm.

All calves received at least three feedings of colostrum and were injected with 1 cc of Duravite (500,000 IU vitamin A, 75,000 IU vitamin D_2 and 50 IU vitamin E).

For specific experiments, four calves were allotted to each of the following treatments.

Experiment 1

Lot (1) Milk replacer (6.5% fat) was fed at restricted levels to 4 weeks of age (table 1). Calf meal (table 2) was self-fed from 10 days to 10 weeks of age. This feeding program was tested at the University of Alberta from 1961 to 1965 and was used as a control treatment.

Lot (2) Milk replacer was fed at restricted levels to 4 weeks of age (table 1). The calves were self-fed pre-starter (table 2) from 10 days to 6 weeks of age, and calf meal from 6 to 10 weeks of age.

Lot (3) Milk replacer was fed to maximum appetite of the calves to 3 weeks of age, followed by restricted levels to 4 weeks of age (table 1). Calf meal was self-fed from 10 days to 10 weeks of age.

Lot (4) Milk replacer was fed to maximum appetite of the calves to 2 weeks of age, followed by restricted levels to 3 weeks of age (table 1). The calves were self-fed pre-starter from 10 days to 6 weeks of age, and calf meal from 6 to 10 weeks of age.

Lot (5) High-fat vealer (16.0% fat) was fed to maximum appetite of the calves to 2 weeks of age, followed by restricted levels to 3 weeks of age (table 1). The calves were self-fed pre-starter from 10 days to 6 weeks of age, and calf meal from 6 to 10 weeks of age.

Experiment 2

Lot (6) Milk replacer was fed at restricted levels to 4 weeks

Table 1. Feeding schedule for milk substitutes - experiment 1.

(g/feed)

Lot	1		2		3		4		5	
Milk substitute	LL-LE[1]		LL-LE		HL-LE		HL-LE		HL-HE[2]	
Period	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
Age in days:										
4	140	140	140	140	250	250	250	250	250	250
5	140	140	140	140	250	275	250	275	250	275
6	140	140	140	140	275	300	275	300	275	300
7	140	140	140	140	300	325	300	325	300	325
8	225	225	225	225	325	350	325	350	325	350
9	225	225	225	225	350	375	350	375	350	375
10	225	225	225	225	375	400	375	400	375	400
11	225	225	225	225	400	425	400	425	400	425
12	225	225	225	225	425	450	425	450	425	450
13	225	225	225	225	450	475	450	475	450	475
14	225	225	225	225	475	500	475	500	475	500
15	285	285	285	285	500	525		200		200
16	285	285	285	285	525	550		200		200
17	285	285	285	285	550	575		200		200
18	285	285	285	285	575	600		200		200
19	285	285	285	285	600	600		200		200
20	285	285	285	285	600	600		200		200
21	285	285	285	285	600	600		200		200
22	70	70	70	70		200				
23	70	70	70	70		200				
24	70	70	70	70		200				
25	70	70	70	70		200				
26	70	70	70	70		200				
27	70	70	70	70		200				
28	70	70	70	70		200				

[1] Low level - low energy

[2] High level - high energy

Table 1A. Feeding schedule for milk substitutes - experiment 2.

(g/feed)

Lot	6		7		8	
Milk substitute	LL-LE		HL-LE		HL-LE	
Period	AM	PM	AM	PM	AM	PM
Age in days:						
5	140	140	200	200	200	200
6	140	140	225	225	225	225
7	140	140	225	250	225	250
8	225	225	250	250	250	250
9	225	225	275	275	275	275
10	225	225	300	300	275	300
11	225	225	300	300	300	300
12	225	225	325	325	325	325
13	225	225	325	350	325	350
14	225	225	350	350	350	350
15	285	285	375	375	375	375
16	285	285	375	400	375	400
17	285	285	400	400	400	400
18	285	285	425	425	425	425
19	285	285	425	450	425	450
20	285	285	450	450	450	450
21	285	285	450	450	450	450
22	70	70		200		200
23	70	70		200		200
24	70	70		200		200
25	70	70		200		200
26	70	70		200		200
27	70	70		200		200
28	70	70		200		200

Page 25 follows page 28.

Table 2A. Composition of concentrate rations by analyses.

(air dry basis)

Ration	Calf Meal	Pre-starter	Dairy ration
Ingredients %			
Dry matter	90.7	89.4	90.8
Crude Protein	23.40	23.50	13.28
Calcium	0.71	0.90	0.07
Phosphorus	0.80	0.80	0.72

of age (table 1A). Unpelleted calf meal (table 2) was self-fed from 10 days to 10 weeks of age. This was used as a control treatment as in experiment 1.

Lot (7) Milk replacer was fed to near maximum appetite of the calves to 3 weeks of age, followed by restricted levels to 4 weeks of age (table 1A). Pelleted calf meal was self-fed from 10 days to 10 weeks of age.

Lot (8) Milk replacer was fed to near maximum appetite of the calves to 3 weeks of age, followed by restricted levels to 4 weeks of age (table 1A). The calves were self-fed pelleted pre-starter from 10 days to 6 weeks of age, and pelleted calf meal from 6 to 10 weeks of age.

Experiment 3

Lot (9) Milk replacer was fed as in lot 8. Pelleted pre-starter was self-fed from 10 days to 8 weeks of age.

Calves in Experiments 1 and 2 were self-fed a concentrate mixture for dairy cows (table 2) and bone meal from 10 weeks of age to the end of the experiments. None of the calves was fed hay during the experiments.

C. Feeding and handling

For each experiment, the milk substitutes were fed at 7 AM and 4 PM, daily. The required weight of milk substitute was mixed with five parts by weight of warm water. Daily feed consumption was recorded from the start to the end of each experiment.

In experiments 1 and 2 measurements of liveweight, height at withers (mid-line at the top of the shoulders to ground level), and heart girth (body circumference taken directly behind the front legs) were taken on each calf upon arrival at the University farm or at birth and at weekly intervals to the end of each experiment.

All calves were tied in individual stalls at the University of Alberta dairy barn to the end of each experiment. In Experiment 1, one calf from each treatment group was slaughtered at approximately 10 weeks of age and the rest of the calves were slaughtered at approximately 120 days of age. Upon slaughtering, the calves were inspected for abnormalities of the rumen, intestines, heart, lungs, and liver. In Experiments 2 and 3 calves were taken off test at approximately 120 days and 8 weeks of age, respectively.

D. Feeding of Chromic Oxide

1. To estimate fecal excretion

At 4 and 8 weeks of age, all calves in experiments 1 and 2 were placed on a 5-day digestibility study in which chromic oxide was used to obtain an estimate of fecal excretion. From 3 days before each digestibility trial and continuing to the end of each trial, a ration containing 0.5% chromic oxide was fed to all calves. The rations were prepared by mixing 225 g chromic oxide and 100 g corn oil with 45 kg of either the calf meal or the pre-starter (prior to pelleting in experiment 2), as required. At least three grab fecal samples were collected from each calf during each of the 5 days of the digestibility trials.

2. To study diurnal variation

In experiment 2 the grab fecal samples were collected at 8 AM, 1 PM and 5 PM for each of the 5 days of the digestibility trials. These were analyzed to obtain estimates of excretion patterns of chromic oxide, nitrogen and energy.

E. Digestion Studies

All calves in experiment 1 at 4 and 8 weeks of age, and calves in lot 7 and lot 8 in experiment 2 at 4 weeks of age, were placed in

Table 2. Formulation of concentrate rations.

(air dry basis)

Ration Ingredients %	Calf Meal	Pre-starter	Dairy ration
Wheat	69.0	60.90	
Barley			58.0
Oats			25.0
Oat groats		4.10	
Wheat bran			3.0
Soybean meal (44%)	28.0		9.0
Dried skimmilk powder		10.00	
Fish meal		12.00	
Meat meal		1.20	
Stabilized fat		3.00	
Sucrose		5.00	
Molasses		2.40	
Dried molasses			2.0
Ground limestone	0.5	0.20	
Dicalcium phosphate	1.0		
Tri-Na-poly phosphate			2.0
Trace mineral mix[1]		0.15	
Zinc sulphate		0.05	
Iodized salt	0.5	0.50	1.0
Brewers' dried yeast	1.0		
Vitamin B complex mix[2]		0.20	
Vitamin B_{12} (20 mg/kg)		0.10	
Vitamin A (IU/kg)	1760	4400	4500
Vitamin D (IU/kg)	352	440	960
Aureomycin (mg/kg)	33		
TM-20 (.44gm oxytetracyline per Kg)		0.20	

[1]Contains the following minerals per kg: cobalt carbonate, 2.28g; cupric sulphate, 24.50 g; ethylene diamine dihydroiodide, 1.30g; ferrous carbonate, 234.80 g; manganous oxide, 47.73 g; zinc oxide, 2.96 g; ground limestone, 686.43 g.

[2]Contains the following B vitamins per kg: riboflavin, 4.4g; calcium pantothenate, 8.8g; niacin, 19.8g; choline chloride, 21.4g; folic acid, 132.0mg.

metabolism crates (Beacom and Thompson, 1963) for a 5-day period to enable total daily collection of feces and urine (Grieve and Beacom, 1963).

Each day of each digestibility trial , the total feces and/or the individual grab fecal samples from each calf were placed in polyethylene bags and frozen. At the end of each trial, the fecal samples were dried on open trays in a forced-air oven at 60° C for 48 hours. The dried samples were weighed and ground through a 20-mesh screen.

For each calf in experiment 1, two representative fecal samples were obtained from each digestibility trial: one by compositing the total daily fecal samples and one by compositing the grab fecal samples. For each calf in experiment 2, the individual fecal samples were stored for analyses. Digestibility coefficients were calculated in experiment 1 by using fecal excretion measured by total collection and in experiment 2 by using fecal excretion estimated from chromic oxide concentrations in the feed and feces.

Daily urine excretion from each calf during the digestibility periods in experiment 1 was collected in a plastic pail containing 20 ml of 50%(v/v) sulfuric acid. Tap water was used to increase the volume of each daily collection to 2-liters. Five 25 ml aliquots (one per day) were composited to give a single sample representative of the trial.

F. Rumen Fluid and Blood Sampling

a) At the end of each digestibility period in experiment 1, and at 10 intervals from an average of 6 to 55 days of age in experiment 3, approximately 100 ml of rumen fluid was collected from each calf with a stomach pump. Before sampling in experiment 3, the calves were isolated from feed and water for 3 hr after the morning feeding so as to standardize samples between intervals (Nicolai and Stewart, 1965).

The pH of the fluid in experiment 3 was measured immediately with a model 125 Photovolt pH-meter and in both experiments 1 and 3, a 25 ml sample was acidified with 0.1 ml of perchloric acid. The samples were centrifuged at 10,000 rpm for 10 min and the supernatant fluids were stored at $5^{\circ}C$ in sealed vials for analysis of volatile fatty acids.

b) At the same time that rumen samples were collected in experiment 3, blood samples were collected from the jugular vein of each calf with heparinized vacuum tubes. The samples were centrifuged at 10,000 rpm for 10 min and the plasmas were stored at $5^{\circ}C$ in sealed vials for blood glucose analysis.

G. Chemical Analyses

Dry matter and nitrogen were determined on feed and fecal samples and nitrogen was determined on urine samples by AOAC (1960) methods. Gross energy was determined on feed and fecal samples by combustion in a Parr oxygen bomb calorimeter. Chromic oxide in feed and fecal samples was determined by the method of Christian and Coup (1954).

Concentrations of volatile fatty acids in rumen samples were determined by gas-liquid chromatrography (GLC) using a model 600-D Aerograph GLC with a flame ionization detector. A 5.80 μl sample of aqueous rumen fluid was injected directly into a column (3 mm x 1.5 m) packed with a commercial preparation of 5% FFAP on Porapak Q. Helium was used as the carrier gas at a flow rate of 75 ml /min and hydrogen was supplied to the detector at a flow rate of 40 ml/min. An injection temperature of 215° C and an oven temperature of 205° C was used throughout. A flame setting of 1 was maintained and attenuations of 4, 8 and 16 were used as required. A model 44 Microcord recorder was used at a setting of 0.5 millivolts.

Blood glucose analyses were carried out by the Glucostat method (Worthington Biochemical Corporation, Freehold, New Jersey).

H. Statistical Analyses

An IBM 7040 computer in the Department of Computing Science was used to statistically analyze all data. Program BMDO2V was used for the analysis of variance and program G2011 was used for standard deviations and correlations. Duncan's new multiple range test (Steel and Torrie, 1960) was used to test differences between means.

Missing data were replaced by the average value of the group from which the data were missing, and in the analysis of variance, error degrees of freedom were reduced by one for each missing value.

Mean squares obtained by analysis of variance were recorded for each experiment(appendix).

RESULTS AND DISCUSSION

A. Animal Performance in Experiments 1 and 2

Feed consumption and growth data were summarized (table 3) for calves in experiment 1 (lots 1 to 5) and experiment 2 (lots 6 to 8) for specific periods from 0 to 120 days of age.

1. Average feed consumption

0 - 4 weeks: The calves in experiment 1 that were fed restricted levels of milk replacer (lots 1 and 2) or that were weaned at 3 weeks of age (lots 4 and 5) received similar amounts of milk substitutes, but received significantly ($P < 0.01$) less than the calves fed milk replacer to appetite and weaned at 4 weeks of age (lot 3). There were no significant differences in amounts of starter consumed, although there was a trend for the calves that were fed pre-starter to eat slightly more.

The calves in experiment 2 that were fed restricted levels of milk replacer to 4 weeks of age (lot 6) received less than the calves that were fed to appetite and weaned at 4 weeks (lots 7 and 8). The calves that were fed unpelleted calf meal (lot 6) consumed significantly more starter than the calves that were fed pelleted calf meal (lot 7) or pelleted pre-starter (lot 8).

In general, results indicated that calves fed restricted levels of milk replacer to 4 weeks consumed amounts of milk substitutes equal to that of calves fed to appetite and weaned at 3 weeks of age. Feeding high levels of milk replacer to 3 weeks and restricted levels to 4 weeks greatly increased the consumption of milk replacer without decreasing consumption of calf meal. Pelleting greatly reduced the in-

Table 3. Feed consumption and growth characteristics of calves from 0 to 120 days of age

Experiment[1]	1					2		
Lot	1	2	3	4	5	6	7	8
Milk substitute diet	LL-LE	LL-LE	HL-LE	HL-LE	HL-HE	LL-LE	HL-LE	HL-LE
Concentrate diet	CM[2]	PST[3]	CM	PST	PST	CM	CM	PST
Weaning age (weeks)	4	4	4	3	3	4	4	4
No. of calves	4	4	4	3[4]	4	4	4	4
Initial:								
Age on test (days)	4.50	4.25	4.75	4.00	4.50	4.75	4.75	4.00
Wt. on test (kg)	38.5	39.5	39.1	40.1	42.8	41.1	42.9	37.6
Height at withers (cm)	74.1	72.5	73.5	75.2	74.6	74.6	75.1	73.8
Heart girth (cm)	77.9	77.6	78.1	79.6	81.4	79.5	82.4	78.6
Total milk substitutes (kg)	8.96[b]	8.85[b]	15.29[a]	8.68[b]	8.49[b]	8.4[b]	11.5[a]	11.0[a]
Average daily feed (kg)								
0-4 weeks[5]	5.40	6.50	4.60	6.70	6.30	7.60	4.70	4.30
4-8 weeks	1.39	1.21	1.58	1.23	1.14	1.42	1.17	1.02
0-8 weeks	0.95	0.88	1.07	0.89	0.83	1.00	0.88	0.79
8 wks -120 days	2.99	2.63	2.90	2.66	2.66	2.90	2.74	2.80
0-120 days	2.03	1.85	2.09	1.89	1.86	2.01	1.87	1.86
Average daily gain (kg)								
0-4 weeks	0.19[b]	0.22[b]	0.40[a]	0.09[c]	0.18[b]	0.22	0.23	0.21
4-8 weeks	0.66	0.52	0.62	0.68	0.51	0.79[a]	0.44[b]	0.43[b]
0-8 weeks	0.44	0.38	0.52	0.41	0.35	0.51	0.34	0.32
8 wks - 120 days	0.89	0.71	0.90	0.73	0.86	0.87	0.90	0.78
0 - 120 days	0.66	0.54	0.71	0.57	0.61	0.70	0.63	0.57

Table 3. (continued)

Experiment	1					2		
Lot	1	2	3	4	5	6	7	8
Feed/kg gain (kg)								
0 -4 weeks	3.18	2.92	2.06	7.25	3.50	2.54	2.45	2.63
4 - 8 weeks	2.11	2.32	2.56	1.80	2.24	1.79	2.67	2.36
0 - 8 weeks	2.32	2.48	2.22	2.35	2.53	1.96	2.61	2.45
8 weeks-120 days	3.33	3.71	3.19	3.63	3.14	3.33	3.06	3.58
0 - 120 days	3.07	3.29	2.95	3.32	3.04	2.87	2.95	3.29
Height at withers (increase)(cm)								
0 - 4 weeks	2.2	1.3	3.5	2.5	2.9	2.1	2.7	2.1
4 - 8 weeks	2.9	2.9	4.1	1.9	1.8	3.8	3.8	3.8
0 - 8 weeks	5.1	4.1	7.6	4.4	3.8	5.9	6.5	5.9
8 weeks - 120 days	11.4	9.5	11.2	11.1	11.6	13.8	10.6	10.6
0 - 120 days	16.5	13.8	18.8	15.6	16.2	19.7	17.1	15.9
Heart girth (increase)(cm)								
0 - 4 weeks	3.2	1.3	6.8	1.1	0.2	2.4	3.0	4.6
4 - 8 weeks	8.0	5.6	4.4	7.4	4.4	11.0	9.4	4.5
0 - 8 weeks	11.2	6.9	11.2	8.5	4.6	13.4	12.4	9.1
8 weeks - 120 days	21.6	22.1	22.0	18.7	22.4	18.3	18.3	20.7
0 - 120 days	32.8	29.0	33.2	27.2	27.0	31.7	30.7	29.8

[1] Experiments were analyzed separately
[2] Calf meal
[3] Pre-starter
[4] One calf died due to malnutrition
[5] Total starter ration consumed to 4 weeks
[abc] Values with a common superscript, within an experiment, are not significantly ($P < 0.05$) different

take of calf meal and pre-starter to time of weaning. Grieve (1966) found that starter consumption to weaning was greatly reduced when calves were fed high levels of milk replacer to the time of weaning.

4 - 8 weeks: The calves that were fed calf meal (lots 1, 3, 6 and 7) consumed 21% more daily feed during the 4 to 8 week period than the calves that were fed pre-starter (lots 2,4,5 and8). In experiment 1 the reduced pre-starter consumption was believed to be partially due to its many fine ingredients. Pelleting the rations in experiment 2 had an adverse affect on palatability.

0 - 8 weeks: The calves that were fed calf meal consumed an average of 0.98 kg feed, daily, from 0 to 8 weeks of age as compared to an average of 0.85 kg feed, daily, by the calves that were fed pre-starter during that period. Calves in lots 7 and 8 that were fed pelleted rations consumed 12 and 21% less feed, respectively, than the calves in lot 6 that were fed unpelleted calf meal.

8 weeks - 120 days: The calves that were fed calf meal consumed an average of 2.88 kg feed, daily, from 8 weeks to 120 days of age as compared to 2.66 kg feed, daily, consumed by the calves that were fed pre-starter during that period.

0 - 120 days: The calves that were fed calf meal in experiment 1 consumed an average of 2.05 kg feed, daily, to 120 days of age or about 10% more feed than the calves that were fed pre-starter. The calves that were fed pelleted rations (lots 7 and 8) consumed about 7% less feed than the control calves that were fed unpelleted calf meal (lot 6).

Gardner (1967) found that a complex starter (either pelleted or unpelleted) was less palatable than a simple starter. He believed

that calves had a dislike for finely ground ingredients. He found no differences in starter consumption due to pelleting; however, starter consumption was considerably lower than in the present study.

2. Average daily gain

0 - 4 weeks: In experiment 1, the calves that were fed restricted levels of milk replacer to 4 weeks of age (lots 1 and 2), and the calves that were fed vealer to appetite and weaned at 3 weeks of age (lot 5) had similar rates of gain (average of 0.22 kg, daily) to 4 weeks of age. The calves that were fed milk replacer to appetite and weaned at 4 weeks of age (lot 3) had an average daily gain of 0.40 kg, which was significantly ($P < 0.01$) faster than that of the other lots. The calves that were fed milk replacer to appetite and were weaned at 3 weeks of age (lot 4) only gained 0.09 kg, daily, which was significantly slower than that of the other groups.

In experiment 2, all groups of calves gained at a similar rate, which averaged 0.22 kg, daily. Therefore, there was no advantage to feeding high levels of milk replacer when calves were fed pelleted rations, as compared to feeding restricted levels of milk replacer when calves were fed unpelleted calf meal.

On the average, the calves gained approximately 0.22 kg daily to 4 weeks of age which was below normal growth standards of approximately 0.38 kg, daily (Matthews and Tohrman, 1954; NAS - NRC Publ. 1349, 1966). However, gains were equivalent to normal standards when calves were fed milk replacer to appetite to 3 weeks of age plus unpelleted calf meal from 10 days of age and were weaned at 4 weeks of age. This advantage was lost when either pelleted calf meal or pre-starter was fed instead of unpelleted calf meal. There was no advantage to feeding a complex pre-starter

as compared to a simple calf meal. Weaning calves at 3 weeks of age caused a set-back in growth, the set-back being partially overcome by feeding a higher energy milk substitute. The vealer contained 4.67 Kcal gross energy/g as compared to 4.10 Kcal/g for the milk replacer.

4 - 8 weeks: Treatment means for gains by calves from 4 to 8 weeks of age in experiment 1 were not significantly different, although certain trends were evident. The calves in lots 1 and 3 that were fed calf meal gained an average of 0.64 kg, daily, as compared to gains of 0.52 kg, daily, for the calves in lots 2 and 5 that were fed pre-starter. The calves in lot 4 were also fed pre-starter but they gained 0.68 kg, daily. These were the calves that had a reduced gain to 4 weeks of age due to weaning at 3 weeks of age, and it appeared that the higher rate of gain during the 4 to 8 week period of growth was compensatory. Although Leche (1964) observed compensatory growth in calves after a period of restricted milk consumption, Asplund (1963) observed no compensatory growth when calves were set-back in weight during weaning.

In experiment 2, the calves that were fed unpelleted calf meal (lot 6) gained significantly faster than the calves that were fed pelleted calf meal (lot 7) or pelleted pre-starter (lot 8). There was no difference in average daily gains of the calves that were fed pelleted calf meal and pelleted pre-starter.

0 - 8 weeks: In general, the calves that gained faster during the first 4 weeks maintained their weight advantage to 8 weeks of age. Unpelleted calf meal produced faster gains in calves to 8 weeks of age than did pelleted calf meal or pelleted and unpelleted pre-starter.

8 weeks - 120 days: The calves that were fed calf meal (lots 1, 3, 6 and 7) to 10 weeks of age gained an average of 0.89 kg, daily, from 8 weeks to 120 days of age, as compared to gains of 0.77 kg, daily, for

the calves that were fed pre-starter to 6 weeks of age and calf meal to 10 weeks of age. This indicated that the pre-starter-fed calves did not readily adjust to the change of ration. The calves that were fed pelleted rations to 10 weeks of age gained as well from 8 weeks to 120 days of age as the calves that were fed unpelleted ration to 10 weeks of age.

0 - 120 days: In experiment 1, the calves that were fed calf meal (lots 1 and 3) gained an average of 0.68 kg, daily, as compared to daily gains of 0.57 kg for the calves that were fed pre-starter (lots 2, 4 and 5). The calves that were fed milk replacer to appetite and were weaned at 4 weeks (lot 3) gained 0.71 kg, daily or 5.6 % faster than the control calves indicating a definite advantage with respect to weight gained by feeding higher levels of milk replacer.

In experiment 2, average daily gains were reduced by about 10% due to feeding pelleted rations. The average daily gains of calves that were fed pelleted pre-starter were 10% lower than the average daily gains of the calves that were fed pelleted calf meal.

The gains of the control calves in experiment 1, (lot 1) were about 6% lower than the gains in the control calves in experiment 2 (lot 6). This was mainly due to set-backs caused by the two 5-day digestibility studies in metabolism crates with calves in experiment 1. The growth rates of the calves were comparable to normal growth standards of approximately .68 kg, daily, from 0 to 120 days of age (Matthews and Tohrman,1954; NAS - NRC Publ. 1349,1966).

3. Feed Conversion

0 - 4 weeks: Feed conversions by calves during the first 4 weeks of life were extremely variable and were relatively poor due to stresses caused by milk replacer feeding and weaning. The calves that were fed milk replacer to appetite and were weaned at 4 weeks of age (lot 3)

consumed an average of 2.06 kg feed/kg gain which was 30% better than feed conversions in the control calves that were fed milk replacer at restricted levels to 4 weeks of age (lot 1). The calves that were fed milk replacer to appetite and weaned at 3 weeks of age (lot 4) consumed 7.25 kg feed/kg gain which was twice that of the control calves, thus indicating the set-back due to weaning at 3 weeks of age.

4 - 8 weeks: Feed conversion during the 4 to 8 week period averaged 2.21 kg feed/kg gain with no differences between the calf meal and the pre-starter. The calves that had the lowest average daily gain and poorest feed conversion to 4 weeks of age (lot 4) had the highest average daily gain and best feed conversion during the 4 to 8 week period due to compensatory growth.

The average feed conversion of the calves that were fed pelleted rations (experiment 2, lots 7 and 8) was 40% poorer than that of the calves that were fed unpelleted calf meal(lot 6).

0 - 8 weeks: In experiment 1, feed conversions by calves to 8 weeks of age were similar for all the treatments, indicating very little difference in the utilization of the calf meal and pre-starter. Therefore, any differences in gains were due to increased feed intake.

In experiment 2, the feed conversions of the pelleted rations averaged 29% poorer than that for the unpelleted calf meal, thus indicating a decreased utilization due to pelleting.

8 weeks - 120 days: No treatment differences in feed conversion by calves from 8 weeks to 120 days of age were evident.

0 - 120 days: The average feed conversion by calves to 120 days of age was 2.98 kg feed/kg gain for the calves that were fed calf meal (lots 1, 3, 6, and 7) as compared to 3.31 kg feed/kg gain for the calves that were fed pre-starter (lots 2, 4, 5, and 8). As was evident in

the gains to 120 days of age, feed conversion results indicated that calf meal had about a 10% advantage over the pre-starter.

4. <u>Height at withers increase</u>

From 0 to 8 weeks of age, the calves that were fed calf meal (lots 1, 3, 6, and 7) had an average increase in height at withers of 6.3 cm as compared to an average increase of 4.6 cm by the calves that were fed pre-starter (lots 2, 4, 5, and 8). From 0 to 120 days of age, the calves that were fed calf meal had an average increase in height at withers of 18.0 cm as compared to an average increase of 15.4 cm for the calves fed pre-starter. Since the calves that were fed calf meal also demonstrated a faster rate of gain, it would appear that much of this increased gain went into structural development.

5. <u>Heart girth increase</u>

From 0 to 8 weeks of age the calves that were fed calf meal (lots 1,3,6 and 7) had an average increase in heart girth of 12.0 cm as compared to an average increase of 7.9 cm by the calves that were fed pre-starter. From 0 to 120 days of age, the calves that were fed calf meal had an average increase in heart girth of 35.5 cm as compared to an average increase of 28.4 cm by the calves that were fed pre-starter. This was mainly due to the increased feed consumption of the calf meal-fed calves which may have led to increased development of rumen size.

B. Use of Chromic Oxide

1. <u>Use of chromic oxide as an indicator of fecal excretion and of apparent dry matter digestibility by calves at 4 and 8 weeks of age - experiment 1.</u>

Actual dry matter digestibility by calves at 4 and 8 weeks of age and estimates using chromic oxide concentrations in a representative

Table 4 . Use of chromic oxide in estimating fecal excretion and dry matter digestibility by calves at 4 and 8 weeks of age - experiment 1

Lot		1	2	3	4	5
4 weeks:						
Number of days		5	5	5	5	5
Diet		CM	PST	CM	PST	PST
Total collection:						
Total dry matter fed	kg	2.995	2.974	3.491	2.951	2.956
Total feces collected	kg	0.620	0.642	0.838	0.616	0.654
Apparent dry matter digested	%	79.3	77.6	76.0	79.1	77.8
Estimate by chromic oxide in:						
a) Total collected feces						
Estimated fecal excretion	kg	0.748	0.757	0.875	0.688	0.725
Estimated dry matter digested	%	75.0	74.5	74.9	76.7	75.5
b) Grab samples						
Estimated fecal excretion	kg	0.828	0.784	0.755	0.757	0.825
Estimated dry matter digested	%	73.3	76.2	75.5	74.5	70.8
Recovery of chromic oxide	%	82.1	83.7	95.8	89.5	90.2
8 - weeks:						
Number of days		5	5	5	5	5
Diet		CM	CM	CM	CM	CM
Total collection:						
Total dry matter fed	kg	7.241	6.393	8.397	7.344	7.181
Total dry matter excreted	kg	1.237	1.241	1.478	1.344	1.368
Apparent dry matter digested	%	82.7	80.5	82.4	81.7	80.9
Estimate by chromic oxide in:						
a) Total collected						
Estimated dry matter excreted	kg	1.379	1.310	1.658	1.311	1.297

Table 4. (continued)

Lot		1	2	3	4	5
Estimated dry matter digested	%	81.0	79.5	80.3	82.1	81.9
b) Grab samples						
Estimated dry matter excreted	kg	1.246	1.212	1.570	1.303	1.324
Estimated dry matter digested	%	82.1	81.0	81.3	82.3	81.6
Recovery of chromic oxide		88.9	94.4	89.2	102.9	106.5

sample of the total fecal collection (total collected) and in a composite grab fecal sample (grab) were summarized for each treatment (table 4).

Dry matter digestibility coefficients at 4 weeks were underestimated by an average of 2.2 and 3.4 units using the total collected and the grab samples, respectively. Due to a recovery of only 88.2% of the chromic oxide that was fed, the estimated fecal excretions were higher than the actual fecal excretions. As the calves were consuming the starter rations at increasing rates each day due to weaning and ad libitum feeding, daily excretion of chromic oxide overestimated the total daily fecal excretion.

By 8 weeks of age, feed intake and fecal excretion was fairly constant and, as a result, overall average dry matter digestibility coefficients of 81.6, 80.8 and 81.7% for estimates by total collection of feces, by chromic oxide in total feces and by chromic oxide in grab fecal samples, respectively, were obtained. The accuracy of the estimates was greatly improved due to a 96.4% overall recovery of the chromic oxide fed. This recovery was similar to that obtained by other workers for older ruminants (Elam, Putnam, and Davis, 1959; McGuire, Bradley and Little, 1966; Troelsen, 1965).

It was felt that chromic oxide served as a useful indicator of fecal excretion for digestibility studies. The estimates of dry matter digestibility with calves at 4 and 8 weeks of age were highly correlated ($r = 0.83$) with actual dry matter digestibility and the accuracy of the estimates of dry matter digestibility were very good with calves at 8 weeks of age.

2. Excretion patterns of chromic oxide, nitrogen and gross energy by calves at 4 and 8 weeks of age - experiment 2

The concentrations of chromic oxide, nitrogen and gross energy in all the grab fecal samples from each digestibility trial were averaged for

Table 5. Excretion patterns of chromic oxide, nitrogen and gross energy by calves at 4 and 8 weeks of age - experiment 2

(expressed as either a percentage of the mean for periods or for days within a trial)

		Period			Day				
		8 AM	1 PM	5 PM	1	2	3	4	5
Calves at 4 weeks of age:									
Chromic oxide	%	103.0	99.7	97.3 (±1.75)[1]	83.4	96.9	102.4	109.6	107.9(±9.51)
Nitrogen	%	100.9	101.1	98.0 (±1.74)	93.1	93.5	103.5	105.2	104.7(±5.50)
Gross energy	%	99.2	101.3	99.5 (±0.81)	99.5	101.9	100.1	99.3	99.2(±1.00)
Calves at 8 weeks of age:									
Chromic oxide	%	103.3	96.7	100.0 (±2.69)	101.0	106.8	92.6	96.4	103.1(±4.99)
Nitrogen	%	102.1	99.1	98.0 (±1.75)	102.5	99.8	94.3	100.1	103.3(±3.11)
Gross energy	%	100.0	100.0	100.0 (±0.00)	98.0	96.3	103.4	102.1	100.2(±2.60)

[1] Standard deviation

each of the three collection periods (8 AM, 1 PM and 5 PM). For each component, the average concentration for each period was expressed as a percentage of the average concentration for the three periods. Similarly, for each component, the average concentration for each day was expressed as a percentage of the average concentration for the 5 days (table 5).

In general, there was relatively little variation in chromic oxide excretion between periods within the day or between days within the digestibility trials. The greatest variation occurred between days by calves at 4 weeks of age in which the concentration varied from 83.4 to 109.6% of the average from day 1 to day 4. These calves were just weaned at this stage and were consuming dry feed in small quantities and at an increasing rate each day. It was felt that this decreased the rate of passage of feed and chromic oxide and thus the concentration of chromic oxide in the feces had not reached an equilibrium after 3 days of feeding the rations containing 0.5% chromic oxide. This assisted in explaining the low recovery of the chromic oxide that was fed to calves at 4 weeks of age in experiment 1. Chromic oxide should likely have been added to the rations at least 4 days before the first digestibility trial instead of only 3 days. By 8 weeks of age the calves were consuming about 2.0 kg of feed, daily and after 3 days of chromic oxide feeding, the concentration in the feces appeared to be representative of the average.

McGuire, Bradley and Little (1966) found relatively little diurnal variation in 295 kg steers fed a pelleted ration (containing 0.5% chromic oxide) six times a day. Elam, Putnam and Davis (1959) found considerable variation between 3-hour periods within a day and between days when a pelleted ration containing 0.5% chromic oxide was self-fed to 500 lb. heifers. They demonstrated that chromic oxide excretion was related to time of feeding and rate of digestion. The relatively small variation obtained here may have been due in part to more frequent

consumption of food and, therefore, a more continuous rate of digestion.

Nitrogen was excreted at a relatively constant rate during periods within days and during days within the digestibility trials. There was a tendency for the excretion of nitrogen to follow the pattern of chromic oxide excretion. This effect was observed by McGuire, Bradley and Little (1966) in which they found a correlation of 0.88 for nitrogen and chromic oxide excretion by steers fed once daily.

There was almost no variation in gross energy excretion; a trend which was also observed by McGuire, Bradley and Little (1966).

C. Apparent Digestibility of Dry Matter, Nitrogen and Gross Energy and Retention of Nitrogen by Calves at 4 and 8 Weeks of Age.

Digestibility coefficients for dry matter, nitrogen and gross energy in experiments 1 and 2 and retention of nitrogen in experiment 1 were summarized for calves at 4 and 8 weeks of age (table 6).

For each digestibility period in experiment 1, there were no differences between treatments in the digestibility of dry matter, nitrogen or gross energy by calves. The digestibility of dry matter, nitrogen and gross energy increased from average values of 77.5, 69.6 and 75.2%, respectively, at 4 weeks of age to 81.6, 79.9 and 79.8%, respectively, at 8 weeks of age. Between 4 and 8 weeks of age, nitrogen digestibility had increased 15 per cent. Anderson (1966) observed a similar increase in nitrogen digestibility in pigs from 5 to 9 weeks of age due to increasing proteinase activity; this may have been the cause of increased nitrogen digestibility by these calves from 4 to 8 weeks of age. Nitrogen retention increased from an average of 14.5% at 4 weeks of age to 29.9% at 8 weeks of age. Gardner (1967) reported nitrogen retention values of about 40% for 85 kg calves and Stobo, Roy and Gaston (1966)

Table 6. Digestibility coefficients and nitrogen retention values

Lot		Experiment 1: 1	2	3	4	5	Experiment 2: 6	7	8
Calves at 4 weeks of age									
Diet		CM	PST	CM	PST	PST	CM	CM[1]	PST[1]
Number of calves		4	4	4	3	4	4	4	4
Dry matter digested	%	79.3	77.6	76.0	79.1	77.8	78.3[a]	74.6[b]	70.4[c]
Nitrogen digested	%	70.7	69.9	69.2	72.0	68.3	73.4[a]	64.1[b]	60.5[c]
Gross energy digested	%	76.4	75.3	72.8	77.6	75.3	77.6[a]	73.2[b]	70.2[c]
Nitrogen retained	%	13.8	13.0	24.8	9.4	13.3			
Calves at 8 weeks of age									
Diet		CM	CM	CM	CM	CM	CM	CM[1]	CM[1]
Number of calves		4	3[2]	4	3	4	4	4	4
Dry matter digested	%	82.7	80.5	82.4	81.7	80.9	80.1	76.0	76.6
Nitrogen digested	%	83.3	78.2	80.4	80.2	77.2	77.8	77.4	79.3
Gross energy digested	%	80.8	78.2	79.8	79.6	78.6	81.4	73.6	77.6
Nitrogen retained	%	31.2	28.5	30.1	31.6	28.2			

[1] Pelleted rations

[2] One calf died due to bloat and mechanical pneumonia

[abc] Values of the common superscripts are not significantly different ($P > 0.05$)

reported values of 32% for 17-week-old calves fed all-concentrate rations. The lowered retention values found in this study were partially due to the stresses caused by of the metabolism crates as many of the calves lost weight; therefore, considerable metabolic nitrogen would have been excreted. In experiment 1, there were no differences in digestibility of the simple calf meal and the complex pre-starter.

In experiment 2, the digestibility coefficients were 78.3, 73.4 and 77.6% for dry matter, nitrogen and gross energy, respectively, by the 4-week-old calves that were fed unpelleted calf meal (lot 6). These were significantly higher than corresponding values for the pelleted rations (lots 7 and 8). Digestibility coefficients for pelleted calf meal (lot 7) were greater than those for pelleted pre-starter. Pelleting lowered the digestibility of dry matter and energy by calves at 8 weeks of age, but did not affect nitrogen digestion. As in experiment 1, the digestibility coefficients for all components increased from 4 to 8 weeks of age.

In general, the digestibility studies showed that there was no advantage to a complex pre-starter as compared to a simple calf meal. Pelleting tended to decrease the digestibility coefficients; the decrease being greater for the 4-week-old calves. The digestibility of dry matter, nitrogen and energy by calves increased substantially from 4 to 8 weeks of age. Gardner (1967) found a similar decrease in digestibility due to pelleting.

D. Development of Rumen Function

1. <u>Volatile fatty acid levels in rumen fluid from calves at 1 and 2 months of age - experiment 1</u>

The average concentrations and molar proportions of the individual VFA in rumen fluid from calves at 1 and 2 months of age were summarized

Table 7. Treatment means for VFA levels in rumen fluid from calves at 1 and 2 months of age - experiment 1

Lot	1	2	3	4	5
Calves at 1 month of age					
Diet	CM	PST	CM	PST	PST
Concentration(mmoles/100ml)					
Acetate	5.50	3.93	5.03	4.57	4.28
Propionate	4.10	2.13	3.63	3.52	3.35
Butyrate	1.56	1.17	1.41	2.39	1.77
Valerate	0.42	0.49	0.50	0.79	0.50
Isobutyrate	0.06	0.07	0.08	0.04	0.07
Isovalerate	0.06	0.03	0.04	0.07	0.14
Total VFA	11.70	7.77	10.69	11.38	10.11
Molar proportions(%)					
Acetate	47.01	50.58	47.05	40.16	42.33
Propionate	35.04	27.41	33.96	30.93	33.14
Butyrate	13.34	15.06	13.19	21.00	17.51
Valerate	3.59	6.30	4.68	6.94	4.95
Isobutyrate	0.51	0.26	0.75	0.35	0.69
Isovalerate	0.51	0.39	0.37	0.62	1.38
Calves at 2 months of age					
Diet	CM	CM	CM	CM	CM
Concentration(mmoles/100ml)					
Acetate	4.31	3.90	4.97	4.18	4.07
Propionate	2.89	3.07	3.98	4.32	3.67
Butyrate	1.50	1.36	1.32	1.97	1.58
Valerate	0.34	0.36	0.35	0.40	0.42
Isobutyrate	0.06	0.09	0.07	0.13	0.14
Isovalerate	0.04	0.05	0.03	0.21	0.17
Total VFA	9.14	8.83	10.72	11.21	10.05
Molar proportions(%)					
Acetate	47.16	44.17	46.36	37.29	40.50
Propionate	31.62	34.77	37.13	38.54	36.52
Butyrate	16.40	15.40	12.32	17.57	15.72
Valerate	3.72	4.08	3.26	3.57	4.18
Isobutyrate	0.66	1.02	0.65	1.17	1.39
Isovalerate	0.44	0.56	0.28	1.86	1.69

(table 7).

There were no detectable treatment effects for calves at either 1 month or 2 months of age. The concentration of the individual acids and the total VFA were similar at both ages.

The overall average concentration of total VFA was 10.3 mmoles/100 ml at 1 month and 10.0 mmoles/100 ml at 2 months. These are similar to values reported by other workers for older ruminants (Addanki, Hibbs and Conrad, 1966b; Conrad, Hibbs and Frank, 1958; Mackay, 1963). At 1 month of age the overall average molar proportions of the individual acids were 45.9, 31.6, 15.9, 5.5, 0.5 and 0.6% for acetate, propionate, butyrate, valerate, isobutyrate and isovalerate, respectively, and at 2 months of age the corresponding molar proportions were 43.5, 35.8, 14.9, 3.8, 1.0 and 1.0%, indicating that very little change in rumen function occurred from 1 to 2 months of age. These values are similar to molar proportions of 46.2, 27.7, 13.5, 7.0 and 5.6% for acetate, propionate, butyrate, valerate, and higher acids obtained by Stobo, Roy and Gaston (1966) with 16 week-old-calves fed an all-concentrate ration.

Feeding high roughage diets, Addanki, Hibbs and Conrad (1966b) found that maximum total VFA concentrations were not reached until about 8 or 10 weeks of age. At 12 weeks of age the molar proportions of acetate, propionate and butyrate were 64.2, 26.4 and 9.8%, respectively, for calves fed alfalfa hay.

2. <u>Rumen VFA levels in calves from 6 to 55 days of age - Experiment 3.</u>

From concentrations of the individual VFA, molar proportions were calculated (table 8). Graphs of average VFA concentrations (fig. 1) and molar proportions (fig. 2) were used to interpret the results.

Table 8 Mean VFA levels in rumen fluid from calves 6 to 55 days of age - experiment 3

Period	1	2	3	4	5	6	7	8	9	10
Avg. age of calves (days)	6	9	14	16	21	23	30	37	48	55
Concentrations: (mmoles/100ml)										
Acetate	1.58	2.08	2.81	2.28	3.42	2.88	4.31	5.11	5.90	5.44
Propionate	0.49	0.84	1.44	1.30	2.00	2.08	2.91	4.78	4.69	4.61
Butyrate	0.11	0.25	0.27	0.32	0.61	0.76	1.23	1.52	1.10	1.48
Valerate	0.05	0.09	0.13	0.20	0.12	0.36	0.92	0.86	0.44	0.55
Isobutyrate	0.05	0.06	0.03	0.02	0.01	0.06	0.04	0.16	0.08	0.09
Isovalerate	0.05	0.03	0.03	0.00	0.00	0.08	0.08	0.19	0.16	0.07
Total VFA	2.33^{a}	3.37^{a}	4.71^{ac}	4.10^{ac}	6.16^{ac}	6.22^{ac}	9.50^{bc}	12.64^{b}	12.37^{b}	12.24^{b}
Molar proportions:(%)										
Acetate	71.6	63.7	63.4	59.8	57.5	50.5	47.7	42.9	48.0	44.4
Propionate	19.7	23.6	27.7	28.9	31.0	31.5	30.0	37.5	37.4	37.5
Butyrate	3.9	7.1	5.3	6.6	9.4	10.7	12.1	10.9	9.1	12.3
Valerate	1.4	2.1	2.1	4.0	1.5	4.6	8.3	6.3	3.6	4.5
Isobutyrate	1.6	2.0	0.9	0.7	0.5	1.4	0.7	1.1	0.6	0.8
Isovalerate	1.8	1.4	0.7	0.0	0.1	1.1	1.2	1.3	1.3	0.6

^{abc}Values with common superscripts are not significantly different ($P < 0.05$)

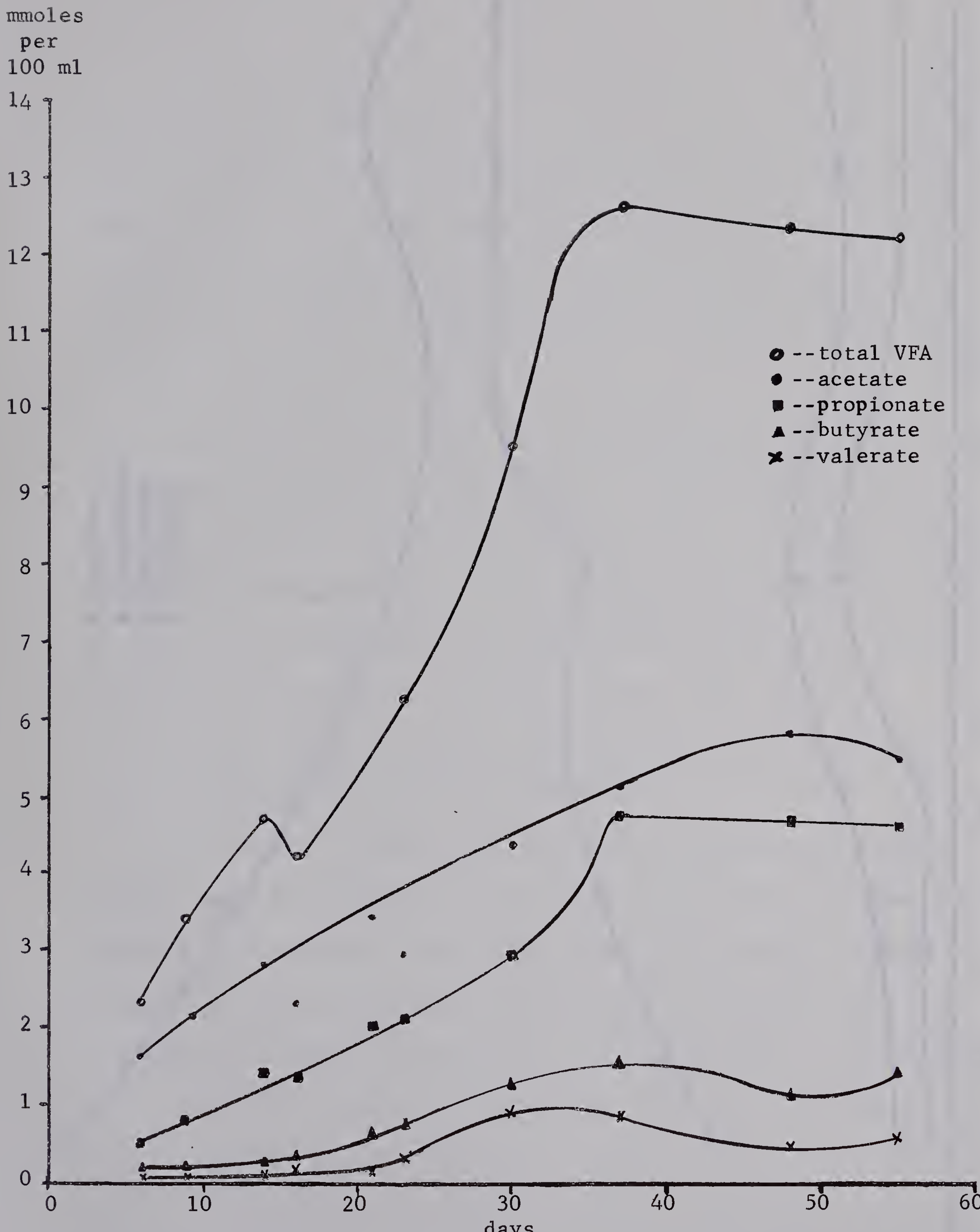

Figure 1. Changes in VFA concentrations with increasing age of calves - experiment 3.

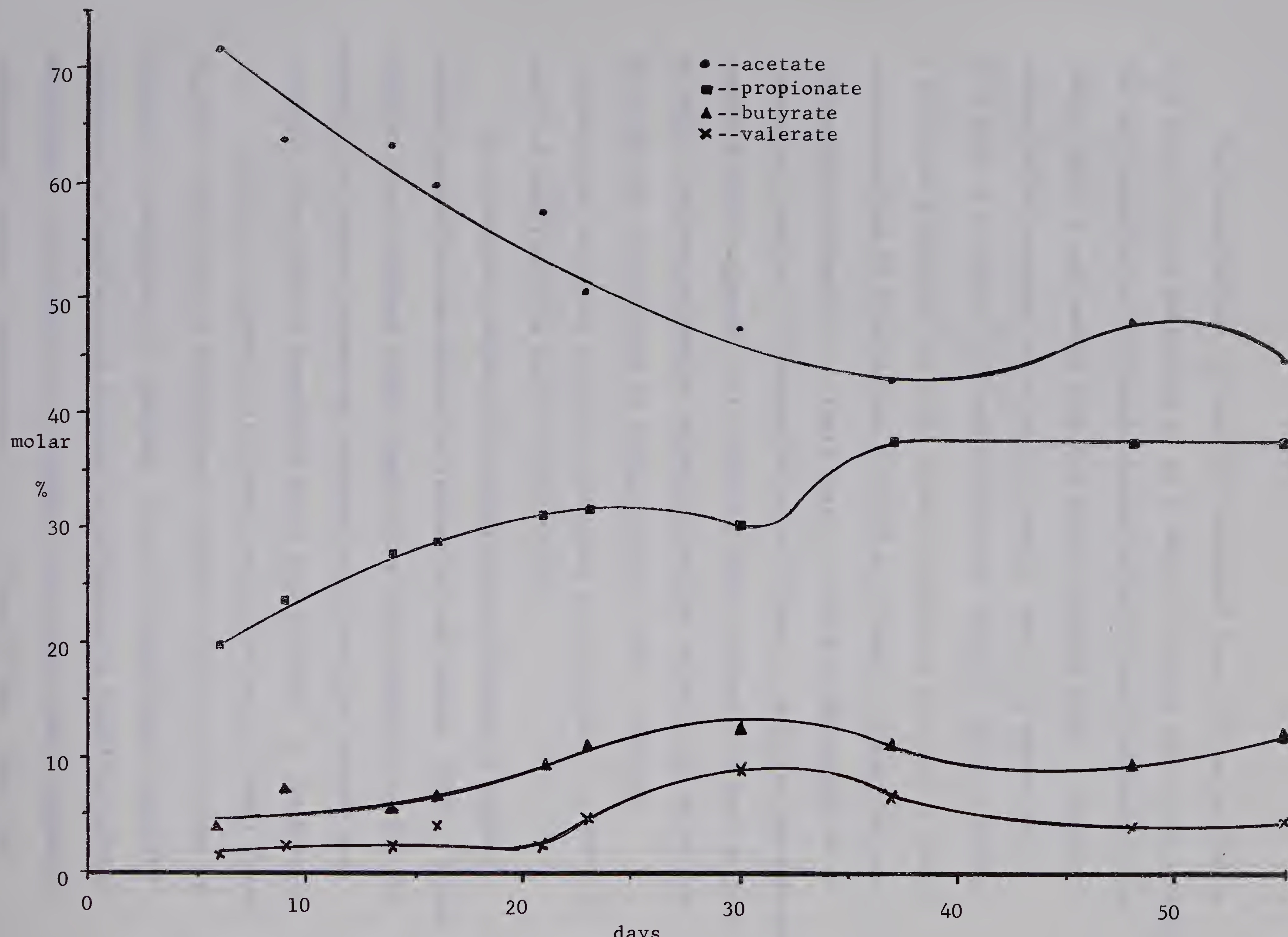

Figure 2. Changes in molar proportions of VFA with increasing age of calves - experiment 3.

The concentration of total VFA increased from 2.32 mmoles/100 ml at 6 days to 12.64 mmoles/100 ml at 37 days. This was due to the tendency for the concentration of longer-chained acids to start increasing later and to reach a peak sooner than the shorter-chained acids. Acetate concentration appeared to increase linearly from 1.58 mmoles/100 ml at 6 days to a peak of 5.90 mmoles/100 ml at 48 days. Acetate became a declining portion of the total acids as indicated by a fall in molar proportion from 71.6% at 6 days to 42.9% at 37 days. Propionate concentration increased at a rapid rate from 0.49 mmoles/100 ml at 6 days to a peak of 4.78 mmoles/100 ml at 37 days. Butyrate concentration remained fairly constant to 16 days and then increased to a peak at about 35 days. Butyrate became an increasing portion of the total acids from 16 to 30 days as indicated by a rise in molar ratio. Valerate concentration and molar proportion remained fairly constant to about 21 days and then rose to a peak at about 30 days.

In the mature ruminant VFA concentrations represent a balance between production and absorption (Stobo, Roy and Gaston, 1966). Sutton, McGilliard and Jacobson (1963) demonstrated that absorption of VFA was negligible in newborn calves and increased only after dry rations were consumed. The order of absorption rates were butyrate > propionate > acetate. Sander et al. (1959) and Sutton et al. (1963) showed that VFA stimulated the development of mucosal tissue in the order of butyrate > propionate > acetate. If it is assumed that increased production of butyrate and valerate is necessary to stimulate mucosal development, the results of the present study suggest that increased development began at approximately 14 - 21 days of age. Since the concentration of these VFA reached a peak at about 30 days of age, it

would appear that a balance between production and absorption of these fatty acids had been reached. The fact that concentrations of acetate and propionate continued to increase beyond 30 days and did not peak until some time later may indicate that mucosal development continued to approximately 40 days of age.

3. Rumen pH levels in calves from 6 to 55 days of age -experiment 3

Rumen pH decreased from a high of 6.9 at 6 days of age to 5.6 at 55 days of age (table 9). Hibbs et al. (1956) demonstrated that pH was inversely proportional to VFA concentrations as indicated also by this study. Sutton, McGilliard and Jacobson (1963) found that the absorption of VFA improved as pH declined.

4. Blood glucose levels in calves from 6 to 55 days of age - experiment 3

There were no statistically significant differences in the concentrations of blood glucose over the 10 periods studied in calves from 6 to 55 days of age (table 9). Blood glucose concentration tended to rise from about 70 mg % at 6 days to 94 mg % at 55 days of age; thus increasing as total VFA increased.

High levels of blood glucose, comparable to those found in monogastrics, are characteristic of young calves fed only on milk. Decreasing levels of blood glucose, leading to hypoglycemia, have been considered a characteristic part of rumen development with ingestion of solid feed (Conrad and Hibbs, 1953; Jacobson, Allen and

Table 9

Rumen pH and blood glucose levels in calves from 6 to 55 days of age - experiment 3

Period	1	2	3	4	5	6	7	8	9	10
Avg age of calves	6	9	14	16	21	23	30	37	48	55
Blood glucose (mg%)	70	84	86	69	81	86	90	93	100	94
Rumen pH	6.9^{a}	6.8^{a}	6.1^{ab}	6.0^{ab}	5.4^{b}	6.3^{ab}	5.9^{b}	5.5^{b}	5.7^{b}	5.6^{b}

^{ab} Values with common superscripts are not significantly($P < 0.05$)different

Bell, 1951; Ndumbe, Runcie and McDonald, 1964). However, Stobo, Roy and Gaston (1966) found that glycemia was affected by the type of ration fed and was not characteristically low. They obtained blood glucose concentrations of 92.8 and 67.5 mg % for calves at 16 weeks of age, fed all-concentrate and all-day diets, respectively. Because Reid (1950) had demonstrated that glucose was produced from propionate in the liver, they felt that concentrate rations which produce high levels of propionate would have a saving effect on blood glucose. Since the blood glucose concentrations in the present study tended to increase as rumen propionate concentrations increased, it appeared that the data would support the above theory.

GENERAL DISCUSSION

Feeding calves milk replacer to maximum appetite to 3 weeks of age and restricted levels to 4 weeks of age greatly increased gains of calves without decreasing unpelleted calf meal consumption to 4 weeks of age as compared to feeding calves restricted levels of milk replacer to 4 weeks of age. Weaning calves at 3 weeks of age resulted in a severe set-back in weight gain to 4 weeks of age as compared to calves weaned at 4 weeks of age. In general, the calves that had the fastest gains to 4 weeks of age maintained their advantage to 120 days of age.

Feeding calves calf meal from 10 days of age to 10 weeks of age increased growth performance to 120 days of age as compared to feeding calves pre-starter from 10 days to 6 weeks of age followed by calf meal from 6 to 10 weeks of age. This was mainly due to increased calf meal intake as feed conversions and digestibilities were similar for both rations. The decreased intake of the pre-starter was believed to be partially due to the unpalatability of its many fine ingredients. Gardner (1967) observed a similar response from feeding a complex commercial starter as compared to a simple starter composed of locally grown grains plus cottonseed meal and minerals.

Pelleting calf rations decreased growth performance in calves due to a combination of decreased feed intake and utilization. Several other workers have found no nutritional advantage to pelleting high-concentrate rations for calves (Gardner, 1967; Lassiter et al., 1955).

Chromic oxide served as a suitable indicator of fecal excretion. However, digestibility coefficients were underestimated due to incomplete recovery of the chromic oxide that was fed. An average recovery of 96.4%

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

for the calves at 8 weeks of age was similar to recovery obtained by other workers (Elam, Putnam and Davis, 1959; McGuire, Bradley and Little, 1966; Troelsen, 1965). Due to a low feed intake by calves at 4 weeks of age, the rate of passage of chromic oxide had not reached an equilibrium between intake and excretion after 3 days of feeding.

There was very little variation in chromic oxide excretion, either between periods throughout the day or between days throughout the digestibility trials. This was felt to be due to a fairly constant rate of passage due to frequent consumption of starter rations (McGuire, Bradley and Little, 1966). Nitrogen excretion was less variable than chromic oxide excretion but it tended to follow the same pattern. There was essentially no variation in gross energy excretion.

The digestibility of rations increased from 4 to 8 weeks of age, with nitrogen digestibility increasing most. This was felt to be due to increased proteinase activity as occurred in pigs from 5 to 9 weeks of age (Anderson, 1966). There were no differences in the digestibility of the calf meal and the pre-starter. There was a decrease in digestibility of rations due to pelleting; the reduction being greatest in the calves at 4 weeks of age.

Rumen VFA levels in the calves had reached adult concentrations by approximately 1 month of age in experiment 1. There was very little change in the molar proportions of the individual VFA from 1 to 2 months of age. The rumen VFA concentrations reached a maximum at about 37 days in the calves in experiment 3; the slight delay may have been caused by a set-back in rumen development due to digestive disturbances encountered and to stresses of frequent collections of blood samples and rumen fluid.

Acetate was the main acid present in calves at 6 days of age and

the other acids increased in molar percentages at the expense of acetate in increasing order of their carbon chain lengths (propionate, butyrate, valerate). The order in which the individual acids appeared to be absorbed and metabolized at a rate similar to which they were produced, as indicated by a peak in concentration, was valerate, butyrate, propionate, and acetate. These results would be expected if longer carbon chained VFA are more readily absorbed and have a greater stimulatory effect on the development of rumen function (Sander et al., 1959; Stobo, Roy and Gaston, 1966; Sutton et al., 1963).

As the total VFA concentration in the rumen fluid increased, pH of the rumen fluid steadily declined. Blood glucose levels remained relatively high, thus not demonstrating the hypoglycemia that was previously believed to be characteristic of rumen development (Conrad and Hibbs, 1953; Jacobson, Allen and Bell, 1951). This effect supported the theory of Stobo, Roy and Gaston (1966) in which concentrate rations that lead to high levels of propionate have a glucogenic effect due to conversion of propionate to glucose in the liver. Thus, calves that are fed high concentrate rations rely on glucose as their major energy source, whereas calves that are fed high roughage rations rely more on acetate.

GENERAL SUMMARY

Experiments were designed to evaluate the performance of young Holstein calves fed either milk replacer(6.5% fat) or vealer(16.0% fat) at high levels to 1 week before weaning followed by restricted levels to weaning at either 3 or 4 weeks of age as compared to feeding milk replacer at restricted levels to weaning at 4 weeks of age (control treatment). Gains of the calves that were fed high levels of milk replacer and weaned at 4 weeks of age were significantly faster than the gains of the control calves. However, gains of the calves that were fed high levels of milk replacer and weaned at 3 weeks of age were significantly slower than the gains of the control calves.

From 10 days of age, calves were fed either a simple calf meal to 10 weeks of age or a complex pre-starter to 6 weeks of age followed by calf meal to 10 weeks of age. The starter rations were fed either as a mash or as pellets. From 10 weeks of age to the end of the experiments at 120 days of age, calves were fed a concentrate mixture for dairy cows plus bonemeal. Performance data to 8 weeks and 120 days indicated that calf meal had a definite advantage over the pre-starter in terms of weight gained. This was due to increased feed intake of the calves that were fed calf meal as their were no differences in feed utilization. Pelleting starter rations reduced performance of calves to 8 weeks and to 120 days due to decreased feed intake and utilization.

Chromic oxide was used to estimate fecal excretion by calves for digestibility studies at 4 and 8 weeks of age. It served as a suitable indicator, although digestibility coefficients were underestimated for the calves at 4 weeks of age due to a low

recovery of the chromic oxide that was fed. Studies of the excretion patterns of chromic oxide, nitrogen and gross energy indicated that there was very little intra-day or between day variation in the concentrations of the various components. This study also showed that chromic oxide should be introduced into rations at least 4 days prior to collection of feces for digestibility studies with calves at 4 weeks of age. A 3-day feeding period was satisfactory for digestibility studies with calves at 8 weeks of age.

Digestibility studies were conducted with calves at 4 and 8 weeks of age either by total collection of feces while in metabolism crates or by estimating fecal excretion by feeding chromic oxide and collecting grab samples. There were no differences in digestibility of dry matter, nitrogen or gross energy by calves fed either calf meal or pre-starter. Pelleting calf rations significantly decreased digestibility; the decrease being greatest for calves at 4 weeks of age. All components and especially nitrogen increased in digestibility by calves from 4 to 8 weeks of age.

Changes in individual and total rumen VFA levels, rumen pH and blood glucose concentrations were studied in four calves from 6 to 55 days of age. The individual VFA started to increase in the order of their increasing carbon chain lengths and they reached their maximum concentrations in the order of their decreasing carbon chain lengths. A peak in concentration was felt to represent the stage at which the individual acid was being absorbed and metabolized at a rate similar to which it was being produced. Rumen pH

decreased as the total VFA level increased. Blood glucose concentration increased slightly and remained relatively high. This effect was felt to be due to a glucogenic effect caused by high levels of propionate.

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Appendix Table A. Experiment 1 - mean squares obtained by analysis of variance

Variables	Total df	Error df	Error mean square	Treatment df	Treatment mean square
Total milk substitutes	18	14	2.714	4	34.406 **
Feed consumption:					
0-4 weeks	18	14	3.386	4	2.953
4-8 weeks	18	14	33.51	4	98.37
8 weeks-120 days	18	14	4.810	4	8.376
0-120 days	18	14	535.8	4	525.4
Gain:					
0-4 weeks	18	14	4.404	4	30.657 **
4-8 weeks	18	14	62.40	4	73.99
8 weeks-120 days	18	14	0.0071	4	0.0374
0-120 days	18	14	60.68	4	234.22
Feed conversion:					
0-4 weeks	18	14	8.328	4	17.949
4-8 weeks	18	14	0.5996	4	0.5539
8 weeks-120 days	18	14	0.0896	4	0.2520
0-120 days	18	14	0.1027	4	0.1242
Height at withers increase:					
0-4 weeks	18	14	2.927	4	2.703
4-8 weeks	18	14	1.325	4	3.672
8 weeks-120 days	18	14	6.232	4	2.835
0-120 days	18	14	6.107	4	13.129
Heart girth increase:					
0-4 weeks	18	14	3.423	4	27.902 **
4-8 weeks	18	14	5.717	4	11.684
8 weeks-120 days	18	14	8.075	4	17.410
0-120 days	18	14	18.153	4	35.100
Digestibility coefficients:					
Dry matter-4 weeks	18	14	7.551	4	10.129
8 weeks	17	13	2.901	4	3.519
Nitrogen --4 weeks	18	14	31.37	4	11.71
8 weeks	17	13	10.58	4	22.25
Energy ----4 weeks	18	14	14.79	4	14.15
8 weeks	17	13	2.688	4	4.164

** $P < 0.01$

Appendix Table B. Experiment 2 - mean squares obtained by analysis of variance

Variables	Total df	Error df	Error mean square	Treatment df	Treatment mean square
Daily milk substitutes	11	9	0.0020	2	0.0158 *
Feed consumption:					
0-4 weeks	11	9	4.185	2	12.386
4-8 weeks	11	9	0.0992	2	0.2120
8 weeks-120 days	11	9	0.3015	2	0.0894
0-120 days	11	9	0.0884	2	0.1940
Average daily gain:					
0-4 weeks	11	9	0.0109	2	0.0008
4-8 weeks	11	9	0.0208	2	0.1697**
8 weeks-120 days	11	9	0.0152	2	0.0143
0-120 days	11	9	0.0130	2	0.0206
Feed conversion:					
0-4 weeks	11	9	2.9050	2	0.2587
4-8 weeks	11	9	0.9396	2	0.8669
8 weeks-120 days	11	9	0.3794	2	0.6260
0-120 days	11	9	0.0998	2	0.1496
Digestibility coefficients:					
Dry matter-4 weeks	11	9	10.82	2	68.51 *
8 weeks	11	9	18.50	2	15.53
Nitrogen -4 weeks	11	9	50.60	2	183.63 *
8 weeks	11	9	15.60	2	35.81
Energy -4 weeks	11	9	8.567	2	56.60 *
8 weeks	11	9	17.74	2	60.47

*P < 0.05; **P < 0.01

Appendix Table C. Experiment 3-mean squares obtained by analysis of variance

	Total df	Error df	Error mean square	Treatment df	Treatment mean square
Total VFA	39	30	8.445	9	63.520**
Rumen pH	39	30	0.4120	9	1.1206*
Blood glucose	39	30	291.7	9	399.0

*P < 0.05; **P < 0.01